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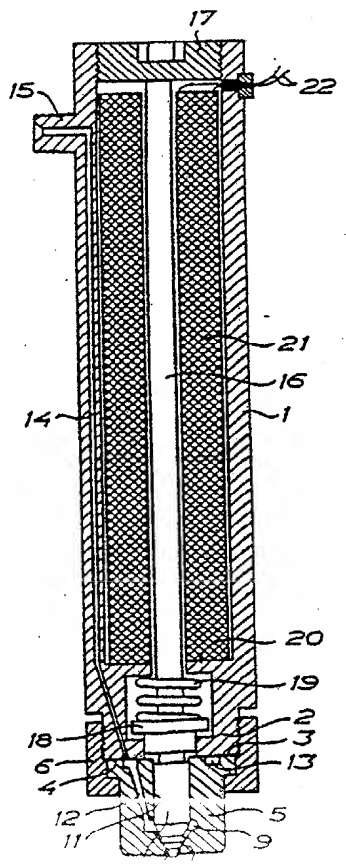
(54) Title: CONTROL MEANS FOR PRECISION CONTROL OF VALVES

(57) Abstract

Control means for precision control of valves having a through opening (7) which is steeplessly adjustable by means of a valve member (10) which is movable within the valve. According to the invention one end of the valve number (10) is rigidly connected to one end of a rod-like control element (16) of giant magnetostrictive material consisting of an alloy between rare earth metals and iron, cobalt or nickel, particularly an alloy between one or several of terbium, dysprosium, samarium and iron. The opposite end of the control element (16) is attached to a rigid supporting structure and is preferably prestressed in the intended direction of movement, e.g. by means of a spring (19). The control element (16) is surrounded by a solenoid (21) for generating a magnetic field acting upon the control element, said magnetic field being proportional to the supply of current to the coil. The control means further include a control device (37) for control of the supply of current to the solenoid in dependence of selected parameters and in accordance with a predetermined program.



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CONTROL MEANS FOR PRECISION CONTROL OF VALVES

The present invention relates to control means for precision control of valves of the kind having a through opening which is steeplessly adjustable by means of a valve member which is movable within the valve.

In different technical fields it is frequently required to provide, by means of electrical control signals, accurate, rapid and flexible control of valves of the kind mentioned initially, in order to control the flow of a gaseous or fluid medium to a recipient, e.g. a prime mover operated by the medium or in order to provide dosage of the medium in accordance with a predetermined program . As means to be used for such purposes many different types of valves are available on the market, ranging from simple magnet valves to servo valves of a rather complicated construction.

In such cases where the intended control requires fast, accurate and flexible adjustment of the valves, the more simple types of electrically controllable valves, e.g. magnet valves etc., can not be used due to unsufficient control characteristics. Due to this it is necessary in such cases to use control valves of a substantially more complex construction, which is often the case, e.g. in servo systems in which the electrically controlled servo valves may be extremely complicated. A frequently used type of servo valves may thus include an electrically controlled pilot valve, controlling a pilot flow, which in turn acts on the valve member of a connected control valve controlling a second control flow, which in turn acts upon the valve member of the main valve in dependence of electrical control signals supplied to the pilot valve. The influence of inertial

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forces, flow resistance and frictional forces acting upon the elements of the servo valve sets up limits for the control characteristics that may be obtained, which often makes it impossible to achieve such control characteristics which otherwise would be desirable.

As an example of a technical field in which there is a long felt need for rapid, exact and flexible valve control means is fuel injection in diesel engines. Injection and ignition of the fuel in diesel engines takes place before the piston during the compression stroke has reached its upper dead centre. This results in a very strong, instantaneous increase in pressure, which not only exerts pistons and bearings to great strain but also generates an opposite torque, which decreases the efficiency of the engine. Due to this a long felt desire is to be able to control the fuel injection during the injection sequence so, that initially only a small amount of fuel is injected whereas the main portion of the fuel is not injected until the piston has reached its upper dead centre. Still another object in connection with fuel injection in diesel engines which, for the reasons previously mentioned, up till now has proved impossible to obtain is the capability to control the injection sequence in dependence of the instantaneous load on the engine for optimizing the energy efficiency at full load as well as at partial load.

The object of the present invention is to provide control means of the kind mentioned initially which renders possible a very rapid, exact and flexible control of the through opening of valves and steepless and extremely finely graded control also of very small movements and rapid sequences, at the same time providing an uncomplicated construction due to the reduction to a minimum of the number of control elements. Another object is to provide control means of the kind

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mentioned in which the influence of inertial forces, flow resistance and frictional forces has been eliminated or substantially decreased.

The objects referred to above are obtained by a design as specified in the appended claims.

In the following the invention will be described with reference to an example of an embodiment according to the invention for controlling fuel injection in diesel engines and with reference to the appended drawings, in which:

Fig 1 is a longitudinal section through a valve in accordance with the invention adapted to control the injection of fuel in a diesel engine, and

Fig 2 illustrates schematicly a system for control of the fuel injection in a 4-cylinder diesel engine in which the control means according to the invention includes valves of the kind shown in Fig 1.

The injection valve shown in Fig 1 includes a cylindrical casing 1, one end of which having a protruding, externally threaded part 2. The externally threaded part 2 has a planar end wall 3 in sealing contact with a corresponding planar end wall 4 of an injection nozzle 5. The injection nozzle 5 is by means of an internally threaded gland nut 6 clamped on the axially protruding part 2 of the casing 1. The injection nozzle 5 is in a manner known per se provided with a nozzle opening 7, surrounded by a seat 8 and an annular chamber 9. The injection nozzle 5 also comprises a jet needle 10 which is displacable axially within a cylindrical bore 11 in the nozzle in which the jet needle is steeplessly adjustable between a closed position in sealing abutment against the seat 8 surrounding the nozzle opening 7, and a fully open position for through flow of fuel through the nozzle opening 7. The annular chamber 9 is by means of a

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passage 12 connected to an annular groove 13 in the upper planar surface 3 in the injection nozzle 5. The nozzle 5 is supplied with fuel through a passage 14 in the cylindrical wall of casing 1, said passage opening into the groove 13 in the upper surface 3 of nozzle 5. The passage 14 extends in the longitudinal direction of the casing 1 and opens into a connection nipple 15 at the opposite end of the casing 1, said nipple by means of a supply line not shown in the figure being connected to a source of fuel, not shown, for supplying the nozzle with diesel fuel under pressure.

According to the invention the injection needle 10, which is formed as a displaceable valve member is rigidly connected with one end of a control element 16 in the form of a rod of giant magnetostrictive material. The opposite end of the control element is fixed to a rigid supporting structure, which in the fuel injection valve shown in Fig 1 is formed by the upper end portion of casing 1. The upper end of the rod-like control element 16 is thus rigidly attached to the end wall 17 of the cylindrical casing 1, e.g. by being screwed into a threaded bore in said end wall 17. The end wall 17 in turn is externally threaded and screwed into the upper end portion of casing 1 which is provided with a corresponding internal thread. The mechanical connection between the lower end of the rod-like control element 16 and the jet needle includes a cylindrical flange 18 extending transversally and supporting one end of a compression spring 19 which extends coaxially with respect to the control element 16. The opposite end of said compression spring 19 is supported in abutment against a partition wall 20 extending transversally within the casing 1, said partition wall 20 being provided with an opening through which the rod-like control element 16 extends, the dimensions of said opening being chosen to

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provide a certain claerance between the rod-like control element and the edges of said opening. The compression spring 19 gives rise to a tensile stress in the rod-like control element 16, and the spring characteristics should be chosen so that a substantially constant pre-stress is maintained in the control element 16 within its intended range of movement. The reasons of this pre-stressing will be discussed in more detail later.

The rod-like control element 16 is further surrounded by a solenoid 21 disposed within the casing 1 in the space which is limited by the lower partition wall 20, the upper end wall 17 and the outer wall of the casing 1. A certain clearance is provided between the inside of the solenoid 21 and the periferal surface of the rod-like control element 16. The electric connections 22 of the solenoid 21 extend transversally through the casing 1 at the upper part thereof and are connected to a source of electric current, not shown in Fig 1, supplying the solenoid 21 with electric current in dependence of digital or analogus electric signals from a control unit, not shown in Fig 1, which controls the supply of current to the solenoid in accordance with the pre-determined program. The source for supplying electric current as well as the control units included in the device are, however, indicated in the schematically illustrated system for control of the fuel injection in a 4-cylinder diesel engine swhown i Fig 2. Before discussing the system according to Fig 2 in more detail the specific properties of the control element according to the invention will be further discussed in the following.

A basic specific feature of the present invention is that the control element 16, as mentioned previously, is made of a so called giant magnetostrictive material, e.g. an alloy between rare earths metals such a samarium

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(Sm),-terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), tulium (Tm) and magnetic transition metals such as iron (Fe), cobalt (Co) and nickel (Ni). This group of alloys presents the largest magnetostriction known so far, e.g. possessing the property to undergo a change in dimension under the influence of a magnetic field, said change in dimension being proportional to the intensity of the magnetic field. It has been found that the magnitude of the magnetostriction in these materials is of a quite different range than is the case in ordinary magnetostrictive materials, e.g. iron-nickel. As an example it may thus be mentioned that for a certain magnetic field iron-nickel undergoes a change in length of 20 - 30 μm/m, whereas an alloy of e.g. terbium-dysprosium-iron undergoes a change in length of 1700 μm/m. The change in length to which said giant magnetostrictive materials are subject under the influence of the magnetic field may be positive or negative, e.g. may for certain of said compositions result in an increase in length and for other of said compositions result in a decrease in length. Both types of giant magnetostrictive materials may be used according to the present invention. Within the group of giant magnetostrictive materials the magnitude of the magnetostriction under the influence of a certain magnetic field varies, and it is of course preferred to use in the embodiments according to the present invention giant magnetostrictive materials having the largest magnetostrictive properties. In the embodiments according to the present invention it is thus preferred to use alloys between terbium, dysprosium and iron or alloys between samarium and iron. Of said alloys the first mentioned gives rise to an increase in length under the influence of an increasing magnetic field whereas the last mentioned alloy undergoes a decrease in

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length under the influence of said magnetic field.

In order to obtain satisfactory results in use the control element should be pre-stressed in a direction opposite the actual direction of movement under the influence of the magnetic field. The reason to this is that a pre-stressing counteracts mechanical hysteres in the magnetostrictive material. The amount of pre-stressing needed is different for different magnetostrictive materials.For a giant magnetostrictive material comprising e.g. an alloy between terbium, dysprosium and iron in the relation $Tb_{0,27}Dy_{0,73}Fe_{1,95}$, the pre-stress together with the load should amount to 12 MPa. Magnetostrictive materials of the kind which undergoes an increase in length under the influence of the magnetic field should be pre-stressed by a compressive stress whereas magnetostrictive materials which decrease in length under the influehce of the magnetic field should be pre-stressed by a tensile stress. The prestress can be provided by means of a mechanical spring having suitable characteristics, as illustrated in Fig 1 in which the spring 19 is adapted to give rise to a tensile stress in the control element 16, as described previously.

When the control element operates, i.e. is subject to a change in length under the influence of the magnetic field, the magnetostrictive material as well as the magnet coil generates heat. The heat generation results in a linear termal expansion of the material. In order to maintain an exact zero-point in the system, the change in dimension due to said heat generation must be compensated for. This may be effected by chosing materials having equal or almost equal coefficient of termal heat expansion or by taking measures to keep the temperature constant. The termal expansion can also be compensated for by means of an active compensation

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system. The time constant for the magnetostrictive movement is very short whereas the time constant for the termal movement is substantially larger' comparatively seen, and due to this the compensation with respect to temperature may easily be obtained by means of a slow adjustment means. If the control system, as schematically illustrated in Fig 2, includes a feed-back system according to which the movement of the control element is measured, e.g. the instantaneous position of the control element is detected, and the electrical signals thus generated are fed back to the control circuit, it is possible to compensate for the linear thermal expansion.

The fuel injection valve shown in Fig 1 operates in the following manner. When current is supplied to the solenoid 21 from the source of electric current, a magnetic field is generated in the solenoid the axial direction of which being parallel with the intended direction of movement of the control element 16. The magnetic field causes a change in dimension of the control element consisting of giant magnetostrictive material. Since the control element in the example illustrated in Fig 1 is presupposed to be made of a giant magnetostrictive material of the kind which undergoes a decrease in dimension under the influence of a magnetic field, the length of the control element 16 decreases. This results in that the injection needle 10, which in the initial position was in sealing contact against the seat 8, is lifted from the seat thus allowing fuel to be injected through the annular injection opening under the influence of the pressure in the fuel injection channel 12. By steepless adjustment of the control signals supplied to the current generating source by means of a control means, not shown, the magnitude of the injection opening 7 is

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steeplessly variable during the injection sequence, thus steeplessly varying the amount of fuel that is injected per unit of time. It should be pointed out that the change of the length of the control element 16 under the influence of the magnetic field takes place under minimal influence of inertial forces etc., which renders possible a very fast, steepless and exact adjustment of the jet needle and consequently an exact adjustment of the amount of fuel injected per unit of time. Although the fuel injection takes place during a very short period of time, the present invention renders possible such an accurate control of the amount of fuel injected per unit of time during the injection sequence which previously could not be obtained.

Fig 2 illustrates, very schematically, an embodiment according to the invention for control of the fuel injection in a 4-cylinder diesel engine, schematically represented on the drawing and referred to under reference numeral 23 and its crank shaft being referred to under reference numeral 24. For fuel injection into each of the cylinders of the diesel engine each of them is provided with a fuel injection valve 25, 26, 27 and 28 of the kind described with reference to Fig 1. In Fig 2 the fuel injection valves 25 - 28 are represented only by the control element 16 and the solenoid 21. Each solenoid 21 is supplied with currect from a separate current generator 29, 30, 31 and 32. Each of those current generating sources is by means of an individual electric control line 33, 34, 35, 36 connected to a separate output on the output side of a control device 37, consisting of a computer. An injection algoritm 40 is registed in the computer, said algoritm exactly defining the injection process in dependance of a number of selected parameters, e.g. the cetane rating, type of load (full load or partial load) etc., said parameters

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being set in the form of panel values 41 on the input side 39 of the computer. The positions of the piston within the cylinders are detected from crank shaft 24 by means of a angle transmitter 42, emitting control signals representing the crank shaft angle, angle of velocity and angle of acceleration, said signals being fed through a line 43 to an input on the input side 39 of the computer. By means of a temperature transmitter the exhaust gas temperature is senced and the signals from the transmitter are fed through line 44 to an input on the input side of the computer. In the embodiment illustrated in Fig 2 the fuel injection valves 25 - 28 are provided with e.g. optical transmitters 45 indicating the instantaneous position of the jet needle of each valve and emitting electrical signals in dependence of the respective position to inputs 46 - 49 on the input side of the computer. This provides a positional feed-back enabling a position control independent of influence of temperature fluctuation, so that coincidence between desired conditions and actual conditions continuously can be secured. The embodiment described above thus illustrates the possibilities available by using the control means according to the present invention e.g. for controlling the fuel injection in a diesel engine in an accurate, rapid and flexible way in order to provide improved efficiency and decreased wear, and at the same time enabling a flexible adjustment to different service conditions.

The invention, which above has been described with reference to an embodiment referring to fuel injection in diesel engines, is by no means limited to this particular field but may be applied in many different fields in which there is a need of accurate control of valves of the kind having a through opening which is steeplessly adjustable by means of a valve member

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movable within the valve. The invention is particularly well adapted for use in valves in which the control movement of the valve member has a limited magnitude in absolute figures, but within the scope of the invention also such embodiments are conceivable, in which the change in length of the magnetostrictive control element is amplified into a movement having an increased magnitude by means of known amplification mechanisms ranging from a simple lever mechanism to more sophisticated systems.

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CLAIMS

1. Control mechanism for precision control of valves, the through opening of which being steeplessly adjustable by means of a valve member (10) which is rigidly connected to one end of a control element, c h a r a c t e r i z e d in that the control element comprises an element, preferably in the form of a rod of giant magnetostrictive material consisting of an alloy between rare earth metals and iron, cobalt or nickel, particularly an alloy between one or several of terbium, dysprosium,, samarium, and iron, the opposite end of said control element (16) being attached to a rigid supporting structure, and in that said control element (16) is surrounded by a solenoid (21) generating a magnetic field variable in dependence of supply of current to the solenoid (21), and a control device (37) adapted to control the supply of current to the solenoid in accordance with a predetermined program in dependence of selected parameters and thus, during the entire flow process control the instantaneous magnitude of the through opening of the valve.

2. Control means according to claim 1, c h a r a c t e r i z e d in that the control element (16) is being pre-stressed in its intended movement direction.

3. Control means according to claim 1 or 2, c h a r a c t e r i z e d in that said control element (16) is made of a giant magnetostrictive material having such a composition that said material undergoes a dimensional reduction when the intensity of the magnetic field increrases.

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4. Control means according to claim 3, characterized in that the control element (16) is made of an alloy between samarium and iron.

5. Control means according to claim 3 or 4, characterized in that the control element (16) is being prestressed by means of a spring (19) providing a substantially constant tensile stress in said control element.

6. Control means according to claims 1 or 2 characterizd in that said control element (16) is made of a giant magnetostrictive material being composed so that said material undergoes a dimensional increase when the intensity of the magnetic field increases.

7. Control means according to claim 6, characterized in that said control element (16) is made of an alloy between terbium, dysprosium and iron.

8. Control means according to claims 6 or 7, characterized in that the control element is being prestressed by means of a spring (19) providing a substantially constant conpressive stress in the control element.

9. Control means according to any of the preceeding claims, characterized in that said control device includes a computer (37) and a control algoritm (40) registered in the computer and corresponding to the desired control program, and a current generating source (29 - 32) connected to said solenoid (21) providing current supply to said solenoid, said computer (37), in dependence of input signals on the computer input side (39) corresponding to predetermined parameters, emitting output signals to said current generator determined by said control algoritm for control of the current

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supplied to the solenoid (21) in accordance with the desired control program.

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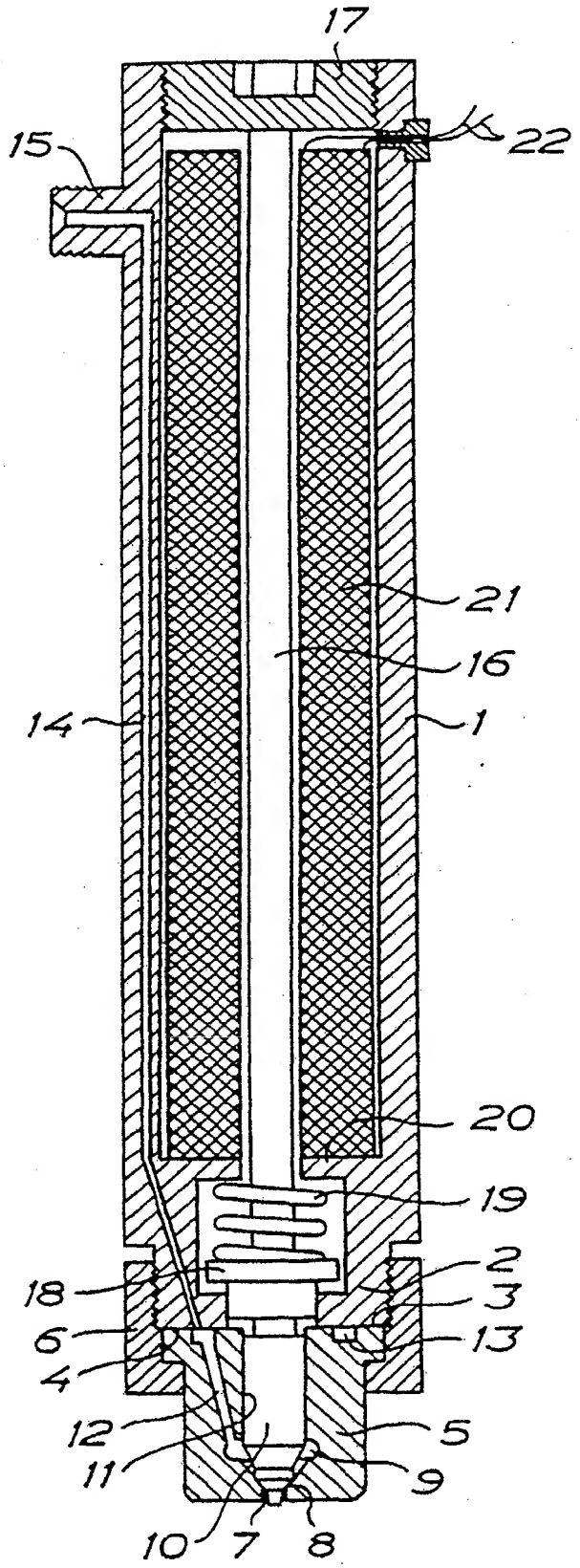

FIG. 1

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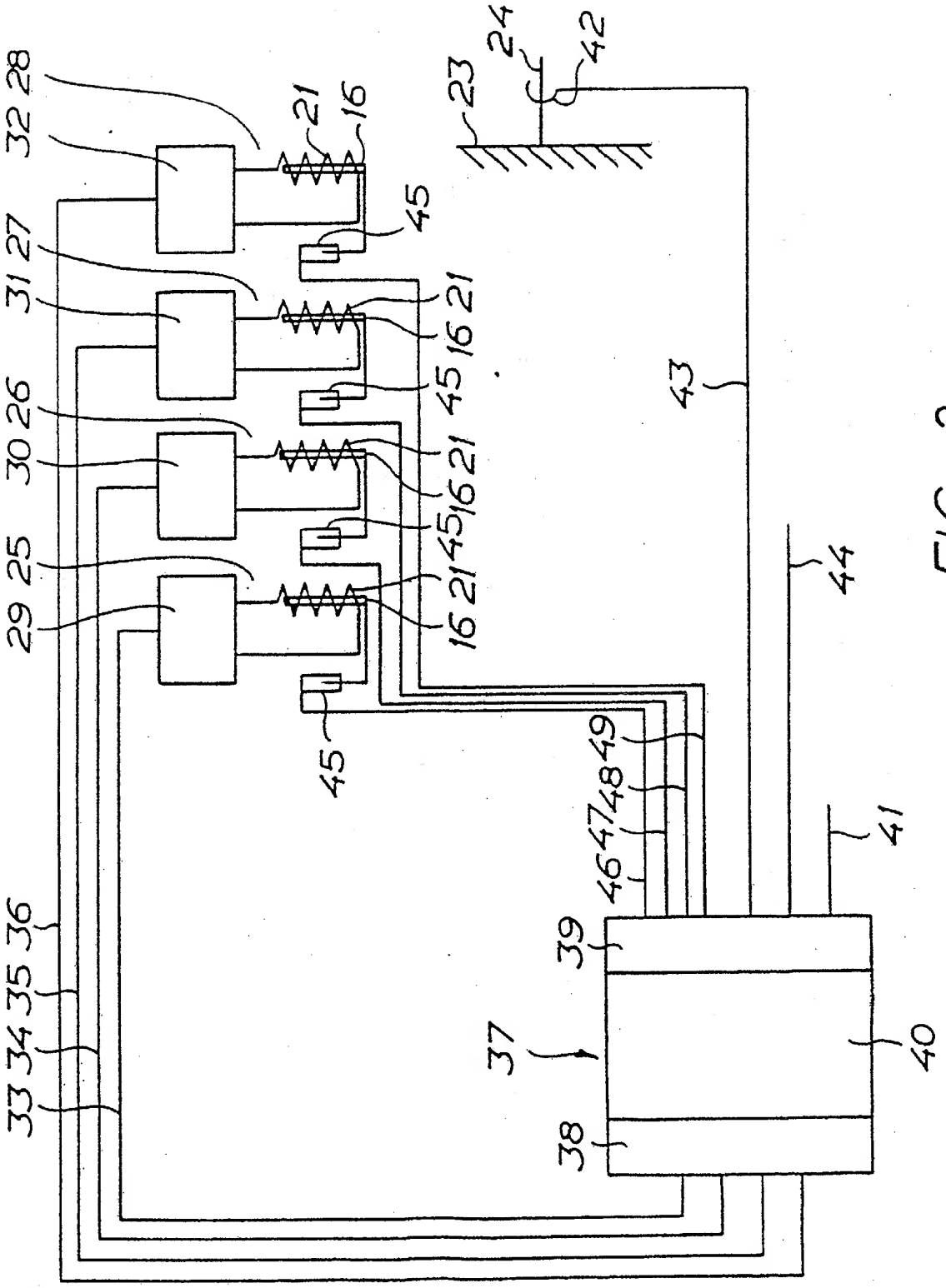

FIG. 2

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INTERNATIONAL SEARCH REPORT

International Application No PCT/SE84/00396

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC [4]

F 02 M 61/10, H 01 L 41/12

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
IPC 4	F 02 M 51/06, 61/00, 04, 10; H 01 L 41/12, 14, 20; B 05 B 1/30
US Cl	239:533.11, 583-585; 310:26; 318:118

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [4]

SE, NO, DK, FI classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category [15]	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	GB, A, 2 056 559 (AUDI NSU AUTO UNION AG) 18 March 1981 & FR, 2463347 DE, 2931874 NL, 8004230 JP, 56024269 US, 4437644	1-9
A	GB, A, 2 082 251 (ROCKWELL INT. CORP.) 3 March 1982	1-9
A	SE, B, 376 103 (WESTERN ELECTRIC COMPANY INC.) 21 October 1971	1-9
A	SE, B, 7806404-5 (GOSUDARSTVENNY) 1 December 1979	1-9
A	US, A, 3 995 813 (BART ET AL.) 7 December 1976	1-9
A	US, A, 4 101 076 (BART) 18 July 1978	1-9

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [3]	Date of Mailing of this International Search Report [3]
1985-02-01	1985 -02- 05

International Searching Authority [1]

Signature of Authorized Officer

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